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Principal Investigator: Diane I. Doser

Title: **Source Parameter Studies of Historical Intraslab and Crustal Earthquakes of Washington and Oregon: Collaborative Research Between the University of Texas at El Paso and Boise State University**

Program Element: I

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SOURCE PARAMETER STUDIES OF HISTORICAL INTRASLAB AND CRUSTAL EARTHQUAKES OF WASHINGTON AND OREGON: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITY OF TEXAS AT EL PASO AND BOISE STATE UNIVERSITY

Diane I. Doser
The University of Texas at El Paso, Department of Geological Sciences, 500 W. University Ave., El Paso, TX 79968
(915)-747-5851 (office), (915)-747-5073 (FAX), doser@geo.utep.edu

TECHNICAL ABSTRACT:
We have collected historical (pre-1966) seismograms of intraslab and crustal earthquakes in order to determine the source locations, source mechanisms and rupture histories of events of the Washington and Oregon region. Digital seismograms of recent (post-1989) earthquakes were used to aid in the interpretation of historic seismograms. We were successfully able to use seismograms of the 2001 Nisqually earthquake as Greens functions to examine the rupture processes of the 1949 Olympia and 1965 Sea-Tac intraslab earthquakes. The 1949 event appears to have a southward direction of rupture propagation with rupture duration of at least 12 seconds. Sufficient seismograms for events in 1939 and 1946 were also available for comparison with the larger intraslab events. Our preliminary results suggest that the 1939 earthquake was an intraslab event, while waveforms of the 1946 earthquake suggest it occurred within the crust. Although we conducted searches at several archives for other events of interest, we were unable to obtain seismograms for many events. Some were too small (magnitude < 5.5) to be recorded at regional distances or seismograms for the events were missing from the archives we searched. In other cases we were able to only obtain one or two seismograms for events that were not located near (within ~50 to 100 km) recent events, which also precluded their analysis. However, we have digitized most legible seismograms in the hope that we will either encounter more seismograms in further searches or that they will be useful to other researchers.

NON-TECHNICAL ABSTRACT

SOURCE PARAMETER STUDIES OF HISTORICAL INTRASLAB AND CRUSTAL EARTHQUAKES OF WASHINGTON AND OREGON: COLLABORATIVE RESEARCH BETWEEN THE UNIVERSITY OF TEXAS AT EL PASO AND BOISE STATE UNIVERSITY

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Diane I. Doser
University of Texas at El Paso, Department of Geological Sciences, 500 W. University Avenue, El Paso, TX 79968
(915)-747-5851, (915)-747-5073, doser@geo.utep.edu

NEHRP Element: I **Keywords:** Geophysics, seismology, source characteristics, seismotectonics

We have compared digital seismograms of recent (post-1989) earthquakes to paper seismograms of earthquakes occurring prior to 1966 recorded at the same (or similar) stations in an effort to determine how similar the older earthquakes were to the well studied recent events. Our results suggest that the older earthquakes within the Seattle-Tacoma region occurred along faults with similar orientations to recent events, although the older earthquakes appear to have longer rupture durations and a different direction of rupture than the recent earthquakes.

Introduction:

The Cascadia subduction zone in Washington and Oregon is created by the collision of the Juan de Fuca oceanic plate with North America at a rate of ~ 4 to 4.5 cm/yr (Riddihough, 1984). Earthquake hazards due to this collision include: 1) M~9 events along the North American/Juan de Fuca plate interface similar to an event occurring in 1700 (Atwater and Hemphill-Haley, 1997; Satake et al., 1996), 2) large intraslab events within the Juan de Fuca plate including the $M_w \geq 6.5$ Olympia (1949), Sea-Tac (1965) and Nisqually (2001) earthquakes, 3) crustal earthquakes within the forearc above the plate interface (e.g. 1993 M_w=5.6 Scotts Mills, Oregon) and 4) scattered crustal events located east of the Cascade volcanic arc (e.g. 1932 M_S=5.8 Milton-Freewater, Oregon). As the population and infrastructure of this region continues to increase, the likelihood of more extensive damage from these earthquake sources will also grow.

In the past century, the largest earthquakes of the Cascadia region have been intraslab events (Figure 1). The recent Nisqually earthquake continues this pattern of large, destructive intraslab events, with damage from this earthquake expected to exceed $0.8 to 2 billion (news reports). These large intraslab events appear to concentrate at 40-60 km depth in two regions of the slab, one located beneath southern Puget Sound, and the other beneath the southern Georgia Strait at edges of an arch in the subducted plate. The largest intraslab events, however, have occurred on the south side of the arch, which may have important earthquake hazard implications for the Seattle-Olympic region. Focal mechanisms (Ma et al., 1996) show T-axes following the down-dip direction of the arch within the plate, consistent with bending of the arch. Metamorphic dehydration reactions (e.g. Kirby et al., 1996; Peacock and Hyndman, 1999) may trigger these intraslab events. However, the lack of intraslab events beneath Oregon suggests that slab stresses, slab composition and/or upper plate composition must also play a role in the intraslab earthquake process (Peacock and Wang, 2000).

Crustal events (Figure 1) in the Cascadia forearc have been less frequent during the past century, but have the capacity for causing more extensive damage than an intraslab event of similar size, due to their shallow depth and the extensive shaking of sedimentary basins that these shallow events may cause. Study of these events may reveal other seismically active shallow structures within the forearc region.

Although population density within the backarc region is lower than the forearc region, continued growth of the entire area increases the hazard for damage from shallow earthquakes. The largest historic earthquake in the Cascadia region during the past 150 years, the 1872 M~7.4 (Malone and Bor, 1979) Lake Chelan (northern Washington) event, may have occurred at shallow depth within the backarc region (Bakun et al., 2001). This event is believed to be shallow due to the occurrence of numerous aftershocks (Milne, 1956), although the lack of observed surface faulting (expected in an earthquake this size) is puzzling, unless it occurred on a blind thrust, as suggested by Bakun et al. (2001). The 1936 Milton-Freewater earthquake (M of 5.8-6.4), located within the backarc along the Washington-Oregon border (Figure 1), is the largest event to have occurred in the backarc region since 1930.

Investigations Undertaken:

This research was devoted to determining the source locations, source mechanisms, and rupture histories of historic (1930-1965) intraslab and crustal events of the Washington and Oregon region. Digital seismograms of recent (1990-2002) earthquakes in this region were used to aid in the interpretation of the historic seismograms. Seismograms of the 2001 Nisqually earthquake were used as Greens functions to more accurately determine the rupture processes of the 1965 Sea-Tac and 1949 Olympia earthquakes.

We collected digital data for recent earthquakes occurring in the vicinity of historic events of interest (Figure 1 and Table 1). Collaborator Jim Zollweg visited seismogram archives at the University of Washington, Berkeley and Denver in 2002 and 2003 and sent us scanned images of all historic seismograms he collected. In July of 2003 further copies of paper seismograms were collected at the Caltech seismogram archives. We also received copies of seismograms from observatories located in Japan, Australia, South America and Europe. Most paper copies of seismograms have been hand digitized. Scanned seismograms were digitized from the scanned images, unless they were very faint, which then required digitization by hand. Table 2 lists all seismograms that were digitized in this study.

We have presented preliminary results of our research at several meetings (see reports section). Ms. Katy Wiest, a graduate student in geophysics, is also completing a M.S. thesis on research related to studies of the Sea-Tac and Olympia earthquakes.

<u>Results:</u>

Intraslab events

The earliest documented intraslab event is the 1939 South Puget Sound earthquake (M~5.8) (Figure 1). Its epicenter appears to be near the 1965 Sea-Tac earthquake (Figure 1). We were able to collect 8 seismograms for this earthquake (Table 2), most recorded by short period instruments (seismometer periods < 5 sec). Depth phases (pP) observed at Saint Louis, Florissant and Little Rock suggest a focal depth of 55t to 63 km for this event. Figure 2 compares seismograms recorded at St. Louis, Missouri for the 1939 South Puget Sound (Wood-Anderson instrument) and 1949 Olympia (Sprengnether long-period instrument) earthquakes and recorded at Florissant, Missouri for the 1939 (Wood-Anderson instrument) and 1965 (Galitzin-Willip instrument)Sea-Tac earthquakes. The seismograms of the 1939 event seem more similar to those of the 1965 Sea-Tac earthquake than the 1949 Olympia event. Although the 1939 event has been assigned a surface wave magnitude 5.8, its body and surface wave amplitudes are 4 to 8 times greater than the 1946 Puget Sound earthquake (an event also assigned a surface wave magnitude of 5.8 and located < 25 km from the 1939 epicenter) at all stations/instruments in common between the events. Thus we feel the moment-magnitude of the 1939 event is likely higher than 5.8. Bakun et al. (2002) estimated an intensity magnitude of 5.7 for the 1939 event; however their estimate was based on a focal depth of 30 km.

The 1946 Puget Sound earthquake (reported M~5.8) has been noted in some catalogs as an intraslab event, although Stover and Coffman (1993) indicate it was a crustal event at ~ 18 km depth. Depth phases (pP) at Pasadena (Figure 4) suggest the event occurred at a depth of 20 to 28 km. This agrees well with the observation of Villaseñor et al. (2001) that the 1946 earthquake occurred at crustal depths. A comparison of seismograms recorded at Pasadena in 1946 and 1949 (Figure 4, both 1-90 Benioff instruments) also support the idea that the 1946 event did not occur within the slab. In addition, seismogram comparisons suggest the event appears to have a smaller magnitude than either the 1936 Milton-Freewater or 1939 South Puget Sound earthquakes

The 1949 Olympia earthquake is the largest intraslab event to have occurred within the past 100 years. Teleseismic waveforms and strong ground motion records of this earthquake have been studied by Baker and Langston (1987), who suggested the earthquake occurred at ~54 km with a strike-slip mechanism and eastward rupture propagation. They estimated a rupture duration of ~12.5 sec and preferred a multiple source model.

Figure 5 compares a Sprengnether long-period seismogram for the 1949 Olympia event with a broad-band seismogram for the 2001 Nisqually earthquake. Note the high frequency similarities between the two earthquakes. Figures 6 and 7 compare low pass filtered seismograms (0.2 Hz cut-off) recorded at College, Alaska, and Pasadena, California, for the 1949 Olympia event with similarly low pass filtered seismograms for the 2001 Nisqually event. In Figure 6 the initial 25 seconds of the P-wave trains for both events are very similar, however amplitudes begin to grow around 20-25 seconds into the 1949 event. The Pasadena records (Figure 7) show even more similarity between the 1949 and 2001 events, with comparable waveforms recorded for the first 100-150 seconds. The similarities suggest similar focal mechanisms for the 1949 and 2002 earthquakes. Bakun et al. (2002) locate the intensity epicenter for this event south of the instrumental epicenter.

The next step in our analysis was to deconvolve the Nisqually records from the older waveforms in order to better characterize the source differences between events. This is illustrated in Figure 8. First the instrument responses were removed from the vertical components of the Nisqually earthquake recorded at Pasadena and College. The records were then convolved with the response of a long-period Benioff seismometer for the Pasadena seismogram and with the response of a Wenner instrument for the College seismogram. A comparison between the "pseudo Benioff" seismogram for the Nisqually earthquake and the seismogram of the 1949 Olympia earthquake is shown at the top left of Figure 8. Both seismograms have been bandpass filtered from 0.01 to 0.1 Hz. Next, the Nisqually seismogram was deconvolved from the Olympia seismogram to obtain a relative source-time function (RSTF). The time window used for the RSTF is indicated by C1 and C2 and is essentially the Pg phase. The top right trace shows the resulting RSTF, with a low pass filter of 0.2 Hz and phase shift of 40 sec. These results indicate a relative source duration of 12 seconds for the Olympia event at Pasadena. The lower left of Figure 8 compares the "pseudo Wenner" seismogram of the Nisqually earthquake to the 1949 seismogram recorded at College. Both seismograms have been low pass filtered at 0.2 Hz. The RSTF at College (lower right) indicates a source duration of 20 seconds. These results suggest possible rupture to the south in 1949. This is consistent with Bakun et al. (2002) who locate the intensity epicenter for the Olympia event 55 km south of the instrumental epicenter.

Langston and Blum (1977) used an extensive collection of WWSSN seismograms to analyze the 1965 Sea-Tac earthquake. They found a normal faulting mechanism with a source depth of 63 km and duration of 3 seconds best fit the observed seismograms. Further analysis of the WWSSN seismograms by Ichinose et al. (2003) determined that rupture in 1965 occurred along two asperities with dimensions of 4 and 8 km^2, located 2 km updip and 4 km south of the hypocenter (located at 60 km depth). Their moment-magnitude estimate of 6.6 is comparable to that estimated by Langston and Blum and to the intensity magnitude (6.5) estimated by Bakun et al. (2002).

Figure 9 compares seismograms of the 1965 and 2001 earthquakes as recorded at Matsushiro, Japan. The 2001 seismogram has been low pass filtered (cut-off frequency of 0.2 Hz). Note the striking similarities between these two events.

Crustal Events-Forearc Region

Crustal earthquakes within the forearc region occur in three general areas, the Puget Sound Basin, the St. Helens seismic zone and the Portland-Scotts Mills area (Figure 1). The earthquakes primarily occur at depths of 7 to 30 km, although there are occasional shallow (< 7 km) events. In the Puget Basin earthquakes concentrate in the region above the arch in the Juan de Fuca plate. These earthquakes exhibit strike-slip or reverse mechanisms. The St. Helens seismic zone is characterized by swarm-like sequences, often including several events of similar magnitude. Strike-slip mechanisms are common in this zone. Earthquakes in the Portland-Scotts Mills area are less frequent, showing both strike-slip and reverse faulting. With the exception of the 1993 Klamath Falls sequence, the forearc of central and southern Oregon shows a notable lack of moderate sized earthquakes throughout the past century.

Moderate (M 5 to 5.6) earthquakes have occurred in the Puget Basin region in 1945, 1954, 1957, and December 1962 (Figure 1). The 1945 North Bend earthquake (M_L 5.6, Zollweg and Johnson, 1989) is the largest tectonic event to have occurred within the Washington Cascade Range within the last century. This event triggered small landslides and could be considered typical of events likely to trigger more massive landslides in other parts of the Cascades (e.g. Mt. Rainier region).

The 1945 event was the only historical crustal earthquake (besides the 1946 event) within the Puget Sound region to be well recorded well at distances beyond 3°. Depth phases (pP) suggest a focal depth between 20 and 28 km. Comparisons of surface wave amplitudes of the 1945 and 1946 event indicate the 1945 event had a similar or slightly smaller magnitude than the 1946 event, in agreement with previously given surface wave magnitudes of 5.8 (1946) and 5.5 (1945).

Seismograms for the 1954 and 1957 earthquakes were limited to short-period records recorded at Seattle and/or Spokane, Washington (Table 2). The Spokane seismograms were recorded on smoked paper. Records from Seattle were either very noisy (1957) or difficult to see following the first arrival. Comparison of these seismograms to those for the 1945 event confirmed that the 1954 and 1957 events occurred at crustal depths (10-15 km).

The 1962 earthquake was recorded at several more stations (Table 2) than events in the 1950's. Depth phases for this event suggest a focal depth of 20 to 30 km.

Within the St. Helens seismic zone Grant and Weaver (1986) have studied earthquakes of the September 1961 Siouxon Peak sequence (Figure 1) through analysis of local arrival time and first motion information. We were to obtain seismograms from Seattle, Longmire and Spokane for this earthquake (Table 2), which suggested a focal depth of 8 to 12 km for the mainshock of the sequence.

Several moderate (M~5.0) earthquakes have occurred in the Portland region since 1930. We have obtained seismograms from Seattle for only the 1953 (M=5.0) Portland earthquake. The limited depth phase data suggest a focal depth of 10 to 12 km for this earthquake.

Crustal Events-Backarc Region

Earthquakes within the backarc region of Washington and northern Oregon occur at very shallow (< 8 km) depths and often have large aftershock sequences. Reverse faulting is common in backarc Washington, with north-south directed P-axes. Stress directions change rapidly to east-west oriented extension in the backarc region of central and southern Oregon (Zoback and Zoback, 1980) marking the shift to Basin and Range deformation within this region.

The 1936 Milton-Freewater mainshock (Figure 1) is the largest historic event to have occurred within the backarc region in the past 100 years and was accompanied by numerous aftershocks. The earthquake appears to be located in a regional of transitional stress between the reverse faulting of the Columbia Basin/Columbia Plateau (Ludwin et al., 1991) and normal faulting observed in the Blue Mountains (Zollweg and Jacobson, 1986) to the east. We have found seismograms from 7 stations for this earthquake and are still in the process of digitizing and analyzing these records.

Reports Published:

Wiest, K., D.I. Doser, and J. Zollweg, 2003a, Source Processes of Western Washington Intraslab Earthquakes (1939-1965), (abstract), Seismol. Res. Lett. 74, 239.

Wiest, K., T. Theiner, A. Velasco, and D. Doser, 2003b, Source parameter studies of historical and recent earthquakes of the Cascadia Subduction zone and Mendocino Triple Junction region, Eos Trans. Amer. Geophys. Union 84 (46), Fall Mtg. Suppl., abstract S42A-0142, 2003.

Wiest, K.R., D. I. Doser, A. A. Velasco, and J. Zollweg, Source processes of Washington intraslab earthquakes (1939-1965), Seismol. Res. Lett. 75, 278, 2004.

Availability of Data Sets:

Tables 1 and 2 provide lists of digital seismograms (post-1989 events) and seismograms we have scanned, digitized and/or collected for pre-1989 events during this study. Copies of these seismograms are available from the principal investigator, Dr. Diane Doser, at (915)-747-5851 or doser@geo.utep.edu.

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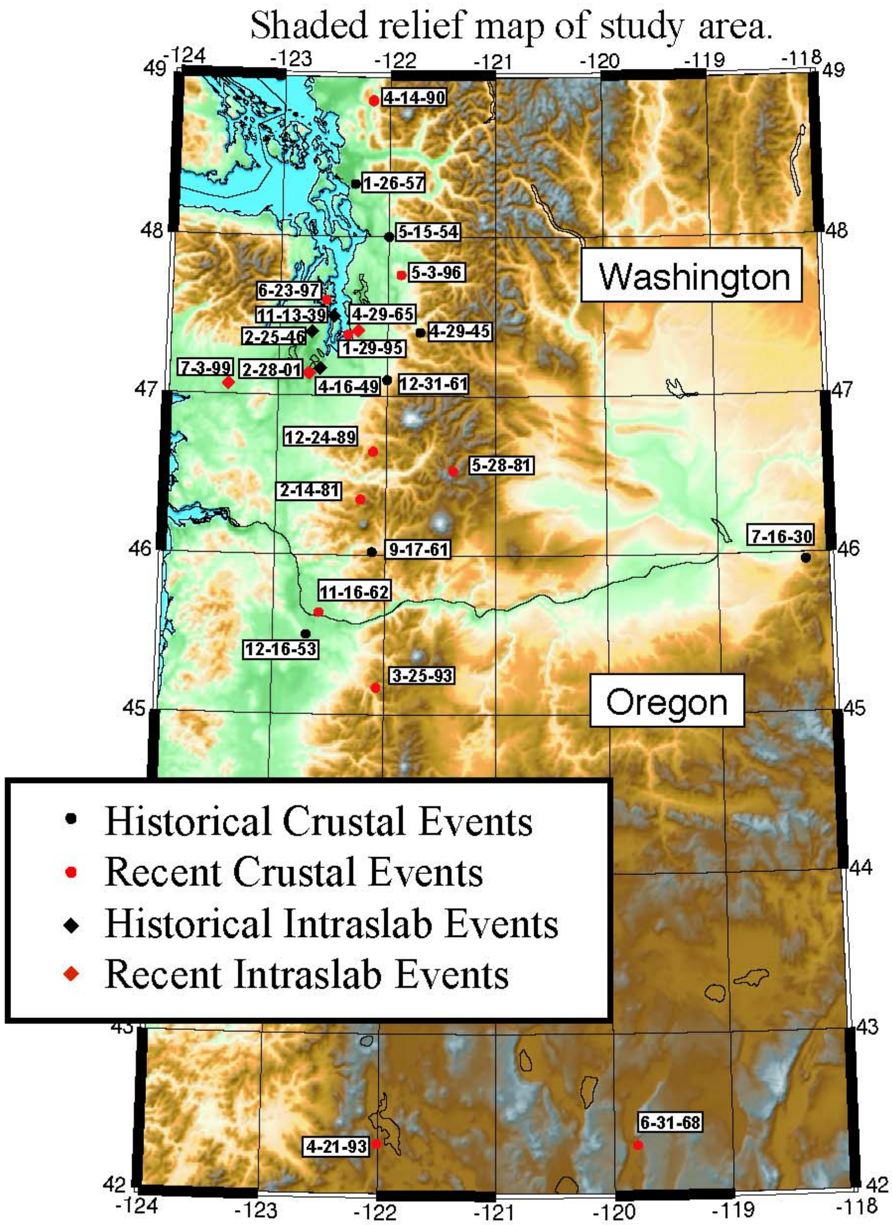
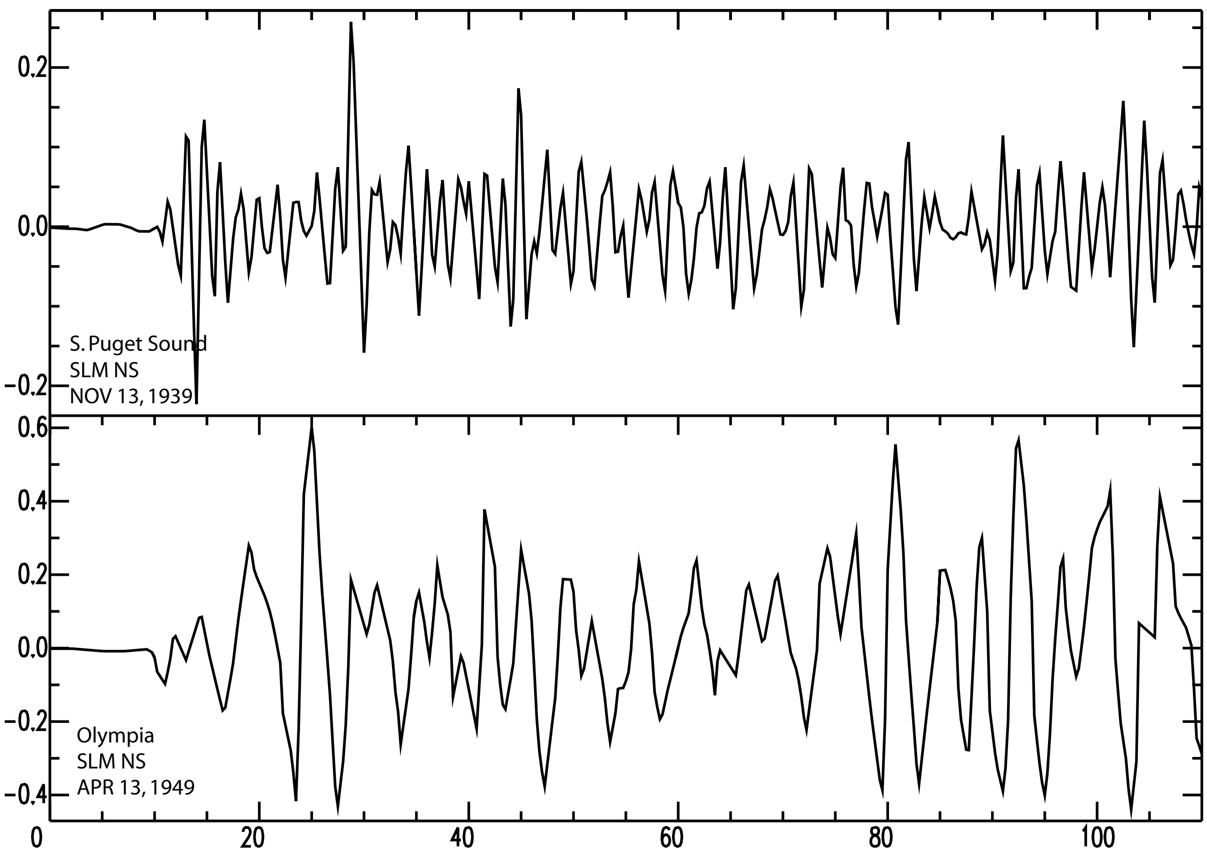


Figure 1 – Map of study area showing historic and recent intraslab and crustal events of interest to this study.

Figure 2 - Comparison of seismograms of the 1939 South Puget Sound earthquake(top) and 1949 Olympia earthquake (bottom) as recorded at St. Louis. The 1939 event was recorded by a Wood-Anderson instrument, while the 1949 event was recorded by a Sprengnether instrument.



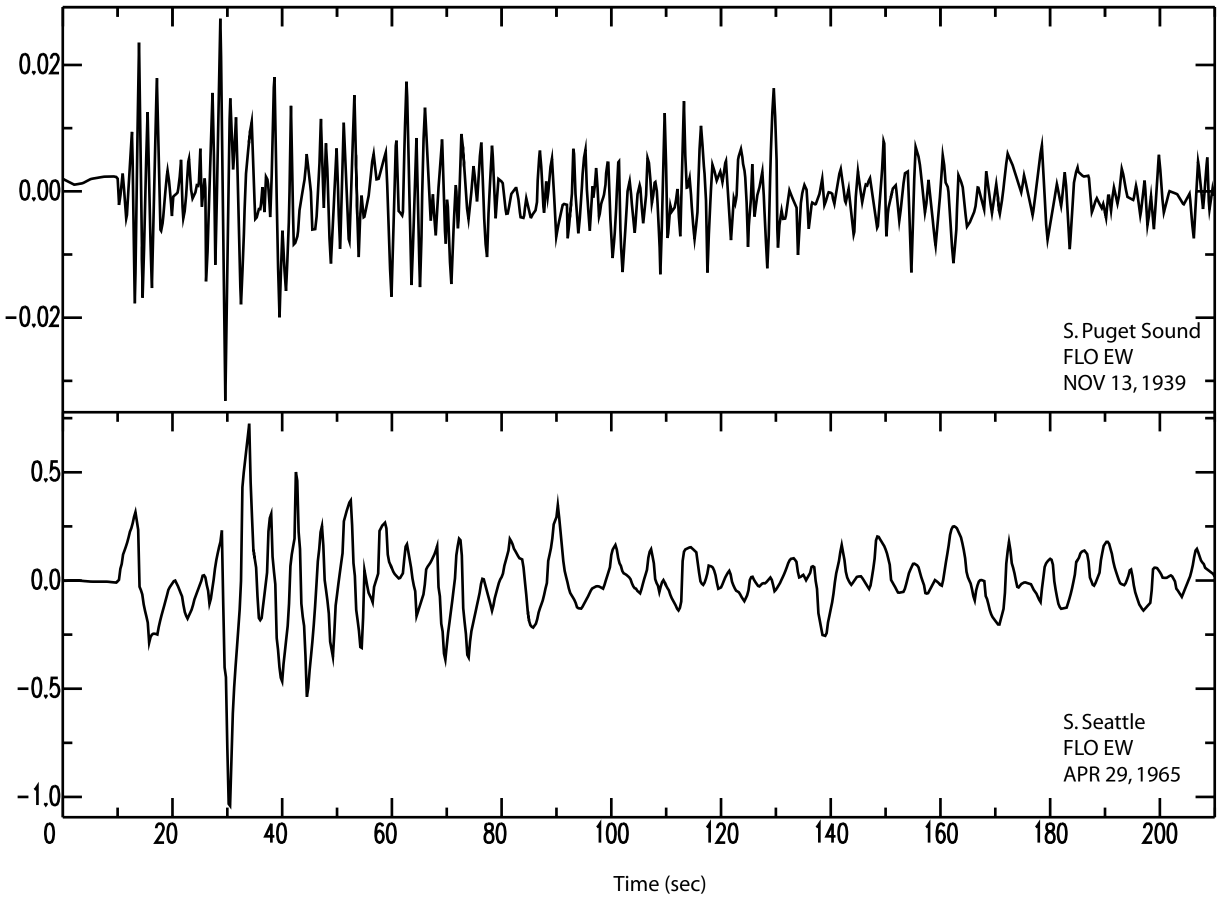


Figure 3 - Seismograms of the 1939 South Puget Sound (top) and 1965 Sea-Tac (bottom) earthquakes recorded at Florissant, Missouri. The 1939 event was recorded by a Wood-Anderson instrument and the 1965 event by a Galitzin-Willip instrument.

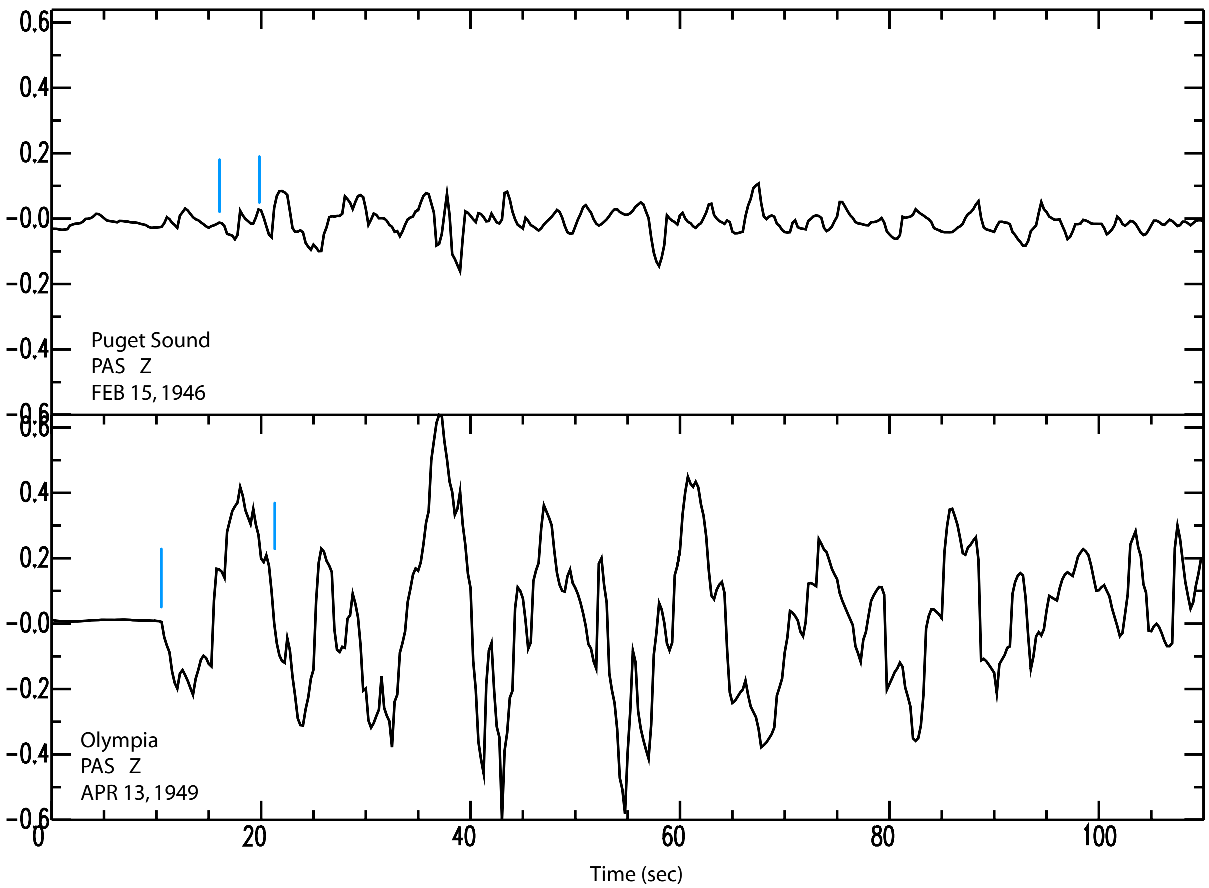


Figure 4 - Vertical component seismograms of the 1946 Puget Sound earthquake (top) and 1949 Olympia earthquake recorded at Pasadena on the same instrument. Blue lines indicate approximate positions of direct P and pP phases.

Figure showing direct comparison between EW components of
2001 Nisqually and 1949 Olympia events recorded in St. Louis, Missouri.

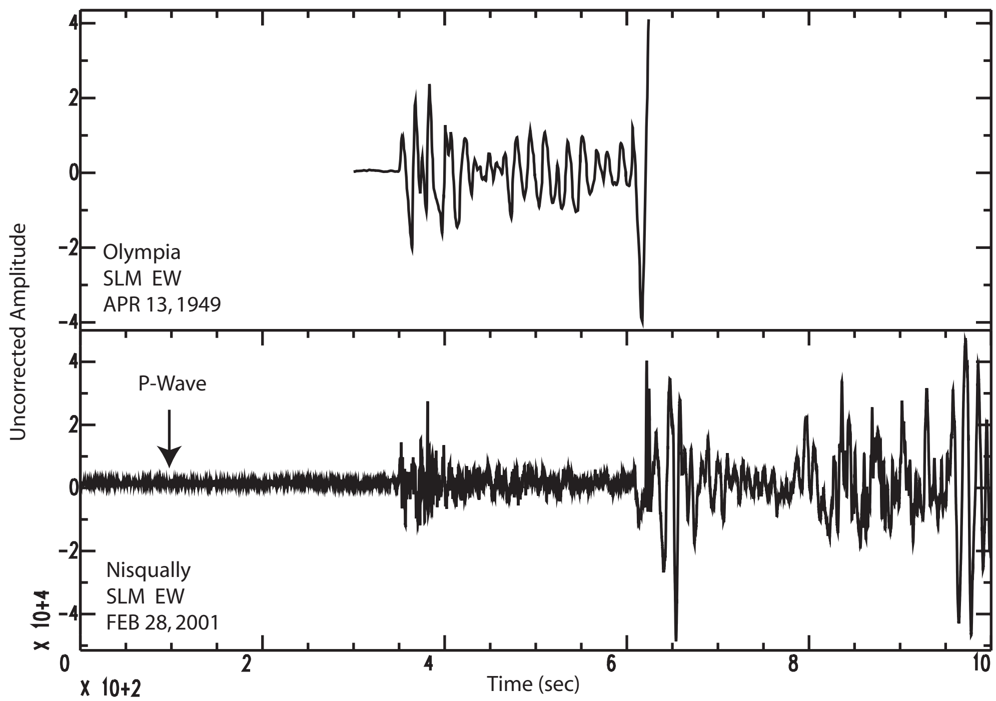


Figure 5 - Top seismogram was recorded by a Sprengnether instrument, bottom seismogram by a broadband instrument.

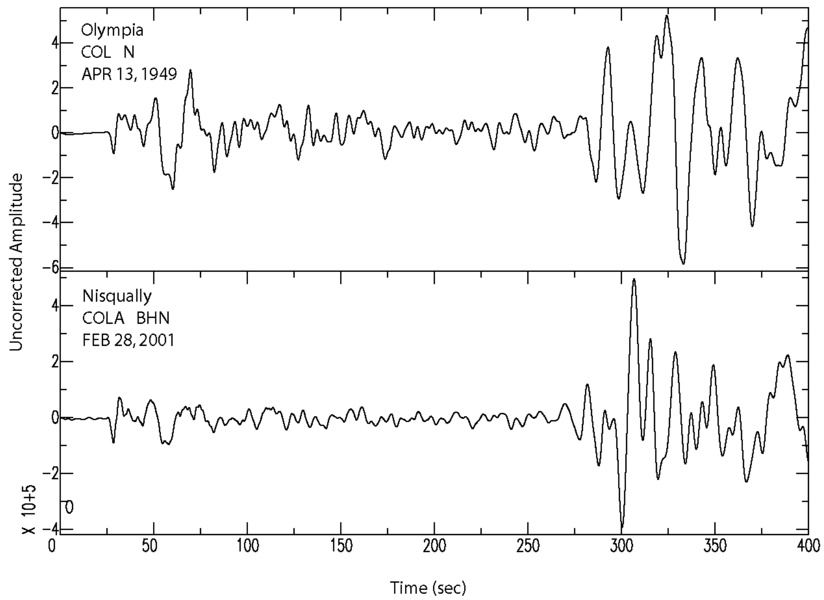


Figure 6- Comparison of seismograms (both low-pass filtered with cut-off of 0.2 Hz) for the 1949 Olympia (top) and 2001 Nisqually earthquakes (bottom) recorded at College, Alaska (north-south component).

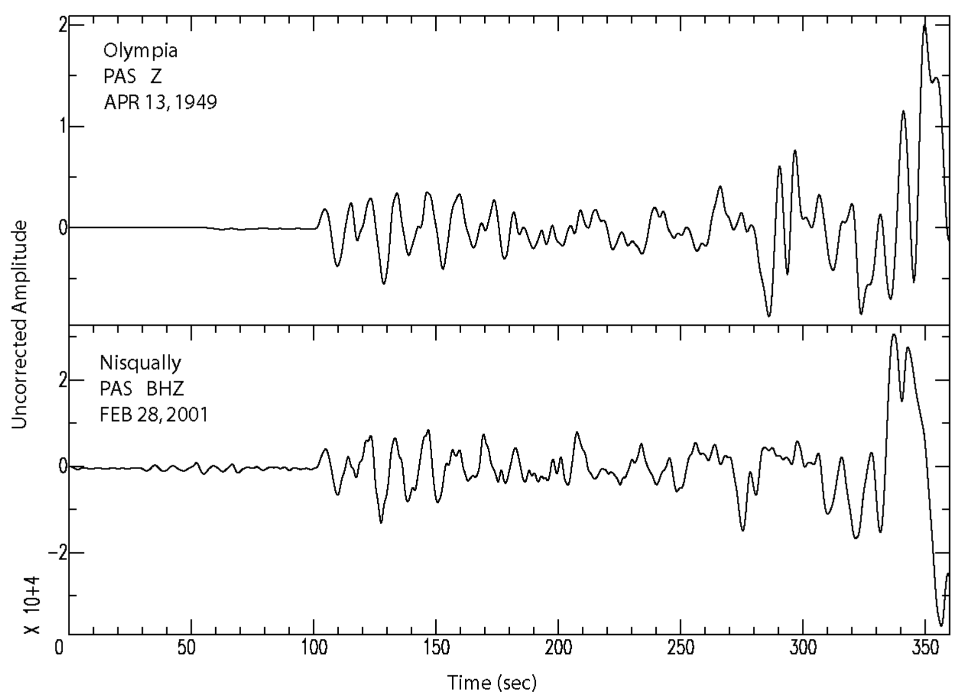
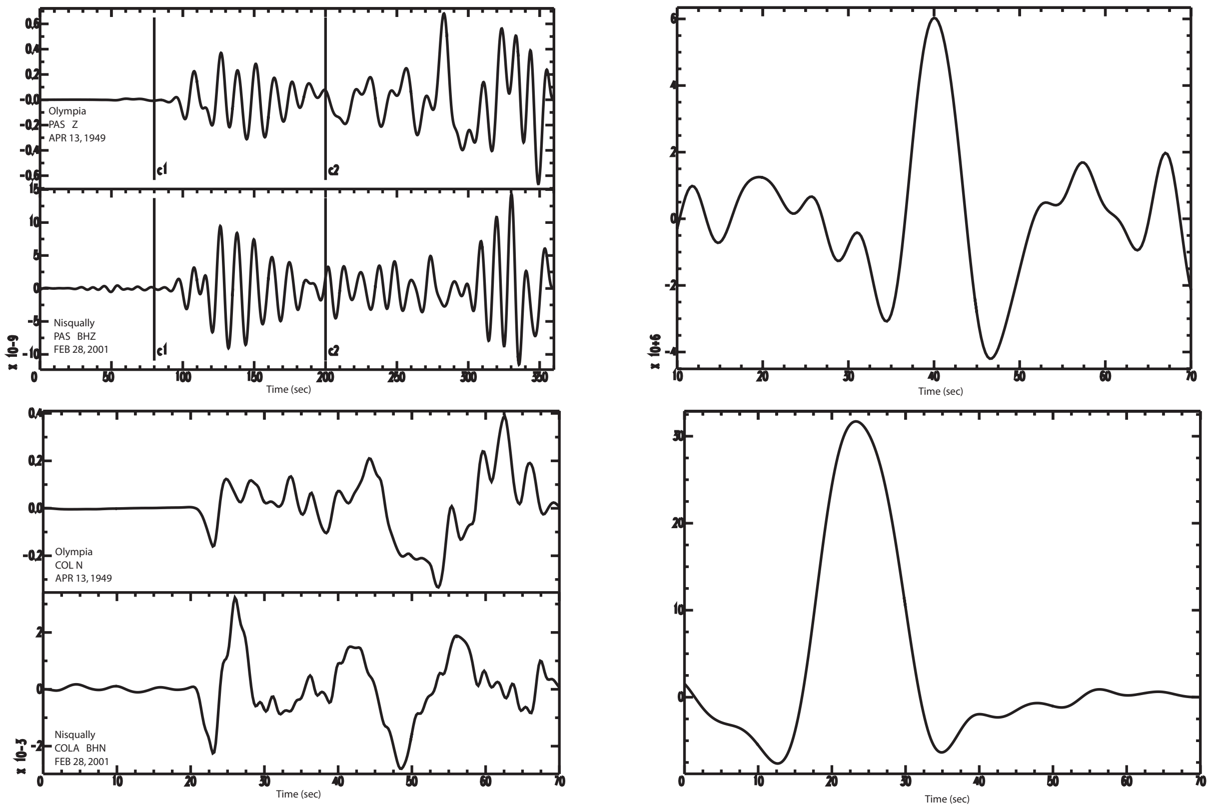


Figure 7 - Comparison of seismograms (both low-pass filtered with cut-off of 0.2 Hz) for the 1949 Olympia (top) and 2001 Nisqually earthquakes (bottom) recorded at Pasadena, California (vertical component).

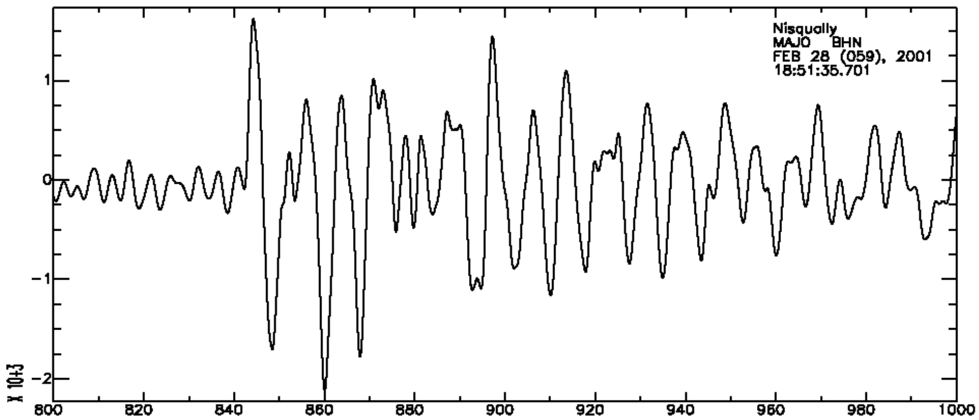


• Left column shows comparison between 1949 Olympia and 2001 Nisqually events recorded at PAS (top) and COL (bottom). We replaced the instrument response of the Nisqually seismogram with that of the instrument running in 1949 for each station. Both PAS seismograms are band pass filtered from 10 to 100 seconds and C1 to C2 represents the time window used in the deconvolution for the relative source time function. Both COL seismograms were low pass filtered at 5 s.

• Right column shows the relative source time functions (RSTF) resulting from deconvolution of the 2001 Nisqually event from the 1949 Olympia event low pass filtered at 5 seconds. The top figure shows the PAS Pg deconvolution with a phase shift of 40 seconds. The bottom figure shows the COL P-wave deconvolution. The RSTF's appear stable giving a relative duration of approximately 12 seconds at PAS and approximately 20 seconds in COL.

Figure 8 - Illustration of deconvolution process for the 1949 Olympia earthquake.

Figure 9 – Comparison of seismograms of the 2001 Nisqually earthquake (top) and 1965 Sea-tac earthquake (bottom) recorded at Matsushiro, Japan (north-south component). The Nisqually seismogram has been filtered using a low-pass filter with 0.2 Hz cut-off.



Copy of historical seismogram of 1965 South Seattle earthquake, M=6.5, recorded near Matsushiro, Japan.

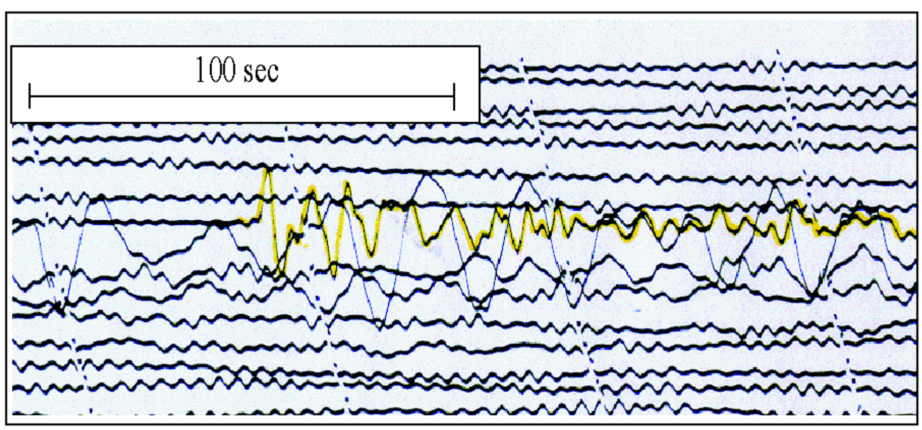


Table 1 – Seismograms of Recent Earthquakes

station	Elk Lake	Goat Rocks	Storm King Mtn.	Deming	Scotts Mills	Klamath Falls
	2/14/1981	5/28/1981	12/24/1989	4/14/1990	3/25/1993	9/21/1993
ALE					*	*
ANMO	*	*	*	*	*	*
BAR						*
CCM				*	*	
COL				*	*	*
COR			*	*	*	*
GSC				*	*	*
HRV			*	*	*	*
ISA					*	*
JAS		*				
LON	*	*				*
MAJO	*	*		*	*	*
PAS			*	*	*	*
PFO				*	*	*
SJG						*
TUC						*

station	Robinson Pt.	Duval	Bremerton	Satsop	Nisqually
	1/29/1995	5/3/1996	6/23/1997	7/3/1999	2/28/2001
ALE	*	*	*	*	*
ANMO		*	*	*	*
BAR	*	*		*	*
BOZ					*
CCM	*			*	
COL	*	*			
COLA				*	*
COR	*	*	*		
DUG			*		*
ELK			*	*	*
GLA		*		*	*
GSC	*		*	*	*
HRV		*			*
ISA	*			*	*
JCT					*
LON	*	*	*	*	*
MAJO	*	*		*	
MBC			*		
MNV			*		*
NEE		*		*	

NEW					*
PAL		*	*		
PAS	*	*	*	*	*
PFO	*	*	*	*	*
PLM				*	*
RES		*	*	*	*
SJG	*	*	*	*	*
SLM			*	*	*
TIN				*	*
TUC	*	*	*	*	*

Table 2 – Seismograms of Historic Earthquakes

Event	Station	Instrument	Component	Status*
7/16/1936	Weston	SP Benioff	Z	P
7/16/1936	Pasadena	1-90 Benioff	NS,EW	D
7/16/1936	Ottawa	LP Benioff	Z	P
7/16/1936	Ottawa	Milne-Shaw	NS,EW	P
7/16/1936	College	Wenner*	NS,EW	D
7/16/1936	San Juan	Wenner*	NS	P
7/16/1936	Florissant	Wood-And.	NS,EW	P
7/16/1936	Saint Louis	Wood-And.	NS,EW	D
7/16/1936	Seattle	SP	NS,EW	S
11/13/1939	Seattle	SP	NS,EW	S
11/13/1939	Spokane	SP	NS,EW	S
11/13/1939	Florissant	Benioff	Z	P
11/13/1939	Florissant	Wood-And.	NS,EW	P
11/13/1939	Saint Louis	Wood-And	NS,EW	D
11/13/1939	Little Rock	Wood-And.	NS,EW	D
11/13/1939	Cape Girardeau	Wood-And.	NS,EW	P
11/13/1939	Weston	Benioff (SP,LP)	Z	P
11/13/1939	Ottawa	Milne-Shaw	NS,EW	D
11/13/1939	Ottawa	Benioff	Z	D
11/13/1939	Pasadena	SP Benioff	NS,EW	P
11/13/1939	College	Wenner	NS,EW	P
11/13/1939	Columbia	Wenner	NS,EW	P
11/13/1939	San Juan	Wenner	EW	D
4/29/1945	Seattle	SP	NS,EW	S
4/29/1945	Florissant	Galitzin	NS,EW,Z	D
4/29/1945	Saint Louis	Sprengnether	NS,EW,Z	D
4/29/1945	Ottawa	Milne-Shaw	NS,EW	D
4/29/1945	College	Wenner	NS,EW	D
4/29/1945	San Juan	Wenner	NS,EW	P
4/29/1945	Weston	SP,LP Benioff	Z	P

2/15/1946	Seattle	SP	NS,EW	S
2/15/1946	Florissant	Galitzin	NS,EW,Z	D
2/15/1946	Saint Louis	Sprengnether	NS,EW,Z	D
2/15/1946	Pasadena	1-90 Benioff	NS,EW	D
2/15/1946	Ottawa	Milne-Shaw	NS,EW	P
2/15/1946	College	Wenner	NS,EW	D
2/15/1946	San Juan	Wenner	NS,EW	P
2/15/1946	Columbia	Wenner	NS,EW	P
2/15/1946	Weston	SP,LP Benioff	Z	P
4/29/1949	Florissant	Galitzin	NS,EW,Z	D
4/29/1949	Saint Louis	Sprengnether	NS,EW	D
4/29/1949	DeBilt	Galitzin	NS,EW,Z	P
4/29/1949	Pasadena	1-90 Benioff	NS,EW	D
4/29/1949	College	Wenner	NS	D
4/29/1949	San Juan	Wenner	NS,EW	P
4/29/1949	La Paz	LP Benioff	NS,EW,Z	D
1/16/1953	Seattle	SP	NS,EW,Z	S
5/15/1954	Seattle	SP	NS,EW,Z	S
1/26/1957	Seattle	SP	NS,EW,Z	S
1/26/1957	Spokane	SP	NS,EW	S
9/17/1961	Longmire	SP Benioff	NS,EW,Z	S
9/17/1961	Seattle	SP	NS,EW,Z	S
9/17/1961	Seattle	LP	NS,EW	S
9/17/1961	Spokane	Wood-And.	NS,EW	S
12/31/1962	Corvallis	LP Benioff	NS,EW,Z	S
12/31/1962	Seattle	SP	NS,EW,Z	S
12/31/1962	Seattle	LP	NS,EW	S
12/31/1962	Spokane	Wood-And.	NS,EW	S
4/29/1965	Weston	SP Benioff	Z	P
4/29/1965	DeBilt	Galitzin	NS,EW,Z	D
4/29/1965	Ottawa	LP Benioff	NS,EW,Z	D
4/29/1965	Florissant	Galitzin	NS,EW,Z	P
4/29/1965	Matsushiro	LP Benioff	NS,EW,Z	D

*D=digitized, P=paper record (not digitized), S=scanned